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CMHC Residential Indoor Air Quality - Parametric Study.

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SYNOPSIS

The purpose of this study was to carry out a mathematical modelling analysis of the effect of indoor pollutant source strengths and ventilation rates on the concentration of pollutants. These concentrations are then compared to various human exposure limits and targets. The modelling was carried out for a variety of ages of residential detached housing for a range of Canadian climatic conditions.

Although a literature search was performed, pollutant source strength data for housing was not generally available. A few houses had been surveyed for CMHC and had concurrent pollutant concentrations and passive tracer gas air change rate measurements. These were used to establish pollutant source strengths or emission rates. The study was directed at building generated pollutants. Soil gas pollutants and combustion appliance spillage were not modelled in this study.

Air change rates including air leakage and mechanical ventilation were estimated using a computerized model. Pollutant concentrations were calculated and analyzed for periods, system types and house types which were potentially undesirable.

For some pollutants including Volatile Organic Compounds (VOCs), no established residential exposure limits have been established. Industrial limits and proposed guidelines are discussed relative to the concentrations predicted. Formaldehyde was compared to Canada's exposure guidelines. Emission limits and ventilation strategies appropriate for housing can be developed through this kind of research work. Further work is needed.

THE AQ1 MODEL

A high degree of variation was known to exist in the airtightness of houses (1,2), the weather conditions in Canada and the sources strengths of pollutants. A relatively simple, fast model was needed to predict effects of various combinations of inputs and estimate indoor air quality for the general population of houses. Multizone models were avoided due to run time and the need for input data not available especially for a wide variety of houses. A single zone, hourly air infiltration model as per Walker and Wilson (3) was selected and combined with a fan/ air leakage interaction model by Palmiter (4) and a pollutant concentration model.

The pollutant concentration is calculated based on previous concentration, air change rate, and source strength as developed by Palmiter and Bond (5). For air change rates greater than 0.0001,

$$C_1 = C_0 e^{-at} + S (1 - e^{-at}) / f,$$

and the integrated average for each hour,

$$C_{av} = (C_0 - C_1) / a + S / f,$$

otherwise,

$$C_1 = C_0 e^{-at} + S (1 - a(0.5 + a/6)) / V,$$

and,

$$C_{av} = (C_0 + C_1) / 2.$$

where C_1 is the new concentration (ppm),
C_0 is the original concentration (ppm),
a is the air change rate (h^{-1}),
t is one hour,
S is the emission rate (mL/h),
f is the flow rate (m^3/h), and
V is the volume of the house (m^3).

This model avoids problems of blow up in concentration for low air change rates. In addition, a minimum difference in indoor/outdoor temperature is a model input for the heating season. Two degrees was used in the simulations as a minimum temperature difference to be expected as a result of solar and internal gains. Integration of a thermal model would be necessary to more accurately model these periods.

Several other features were also included in the model. There is a capability to simulate control of mechanical ventilation based on sensing of the outdoor/indoor temperature difference. Time constants and schedules for emissions can be modelled. The effect of absorption and reemission was not explicitly modelled but could have an effect similar to a longer emission time constant at a lower rate.

PARAMETRIC STUDY

Information on emission rates and especially time constants for emissions were not found for residential indoor pollutant sources. Some limited information performed in CMHC surveys (6,1) was used to establish emission rates. Because these surveys were small, and not randomly selected, they do not provide a true representation of source strengths in general. Examples of source strengths derived from these concurrent passive air change rate and pollutant concentration measurements are shown in Figures 1 and 2. The 5 houses in British Columbia have source strengths 3 times that of the rest of Canada. This anomaly should be investigated. A larger resample in this region would be appropriate. The average for the rest of Canada was used in the simulation of formaldehyde concentrations. For volatile organic compounds (VOCs), the average pollutant emission rate from 20 two year old houses in Saskatchewan and 28 various aged houses in Ontario were used. Toluene had the highest variability in source strength. For the VOCs, the sampling periods for air change rate were one week while the VOCs samplers were exposed for only one day. Source apportionment to building components and activities was not possible due to a lack of data.

Most existing Canadian houses rely on air leakage to provide ventilation. Due to the highly variable nature of accidental leakage individual houses and weather conditions can result in very low air change rates. Several data sets were obtained from recent airtightness testing surveys. Over 400 tests were available as shown in Figure 3. Three regions were selected for data completeness covering all ages of homes and representation of varying climate and average airtightness. The tightest houses are found in the prairie region. The loosest housing in Canada is found in the Vancouver area. Ontario is typical of most other regions of

Canada. Figure 3 displays the variability in this data. Seventy fifth and 90th percentile air tightness's were calculated from the actual data. Because of the small sample size after stratification by age and region, the 90th percentile is not considered as representative as the 75th. Either one is better than the average or the maximum because the they represent a significant portion of houses but are unlikely to be the result of anomalous or erroneous measurements.

Figure 4 displays typical output from the analysis of new houses. Airtightness and volume were assumed to be related. House characteristics and weather were region specific. This reflects the increased airtightness in colder regions. Average pollutant source strengths were used. Source strengths did not show a good correlation to volume. For the simulations, volumes were only varied by less than 15 % which is much smaller than the range of source strengths. Risk of exposure was not estimated in more detail as data on variation in source strengths was not considered sufficient to estimate exposure in more detail. From Figure 4, it is apparent that the predicted hourly concentrations exceed Health and Welfare Canada's guideline for the hourly maximum values in the summer months. Since air conditioning is common in Ontario, this may be a health risk. Monthly average values are also near the Action limit. Residential health limits have not been established for the VOCs but predictions exceed those proposed by Seifert (7). On the other hand concentrations are more than 3 orders of magnitude lower than industrial limits. Also shown on the same figure are values predicted for an indoor to outdoor air temperature controlled ventilation system. A dramatic improvement is seen in the indoor air quality. Similar data for the Prairie and British Columbia regions may not be as critical. The summer values are unlikely to occur due to the low incidence of air conditioning in these areas and high usage of open windows at this time of year. The most critical months are therefore May and October for the Prairies. A temperature controlled set to turn on a 25 L/s ventilator at less than 8 C can maintain average concentration below the action limit. Figure 5 displays hourly output. Although thermal modelling was not performed, very low energy impact is expected to result with this form of ventilation control. Similarly in British Columbia, formaldehyde can be controlled even with a higher formaldehyde source strength.

Since source strengths may be significantly lower for older house, and data was unavailable, maximum emission rates were estimated which could maintain concentrations below the action guidelines for various locations and age groups of housing. If a target of 0.05 ppm is desirable, the emission limit would be proportionately cut in half. Data for British Columbia is shown in Figure 8. Renovations involving flooring, cupboards and furniture would be of most concern. Surveys of materials in typical houses would allow an approximate apportionment of sources and emission targets for each type of material.

CONCLUSIONS

An analysis capability was developed to explore the relationships between various types and rates of pollutant emissions and various rates of air change in detached houses. Rates of air change were modelled from hourly weather data, house airtightness, and mechanical ventilation equipment operation.

As indoor air quality depends on both emissions and ventilation, a balanced approach should be taken. This study has explored possibilities of what emission rates could be tolerated in various housing with air leakage only. For formaldehyde, the maximum tolerable emission rates are achievable. Similarly rates could be determined for other pollutants if health guidelines are available. Ventilation in houses which are not airtight can be controlled by outdoor to indoor air temperature difference. This control strategy significantly reduces the higher concentrations predicted and minimizes the energy cost of ventilation.

Further refinement and calibration of these modelling techniques should be done. More source strength or emission rate data is required including duration of emission and material quantification. Quantification of materials will be necessary to develop emission rates for each type of material in a typical house. Ventilation control by temperature difference has good potential especially in conjunction with retrofit sealing and should be field tested.

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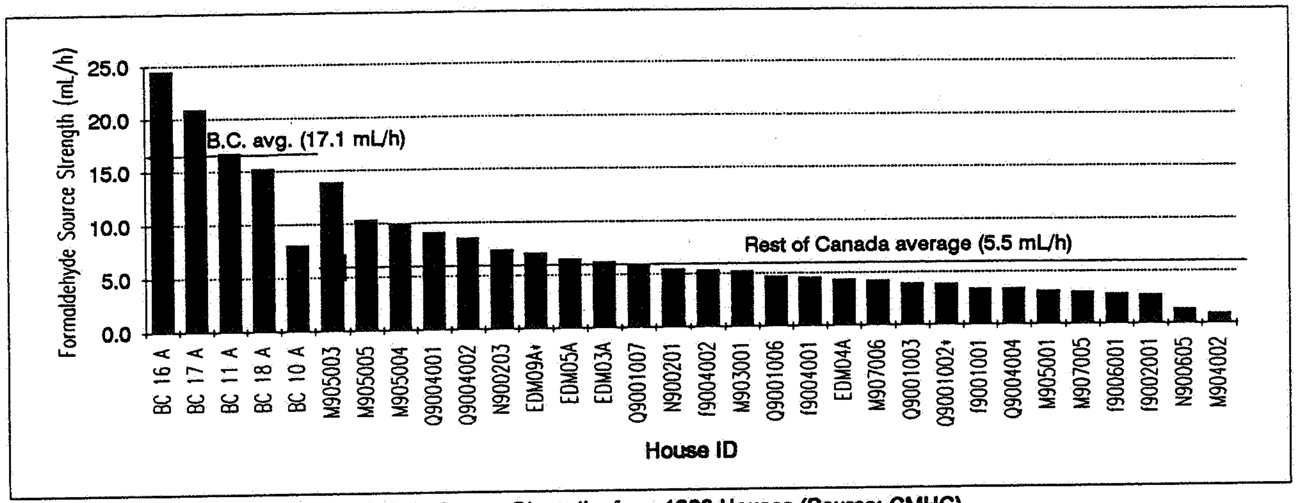
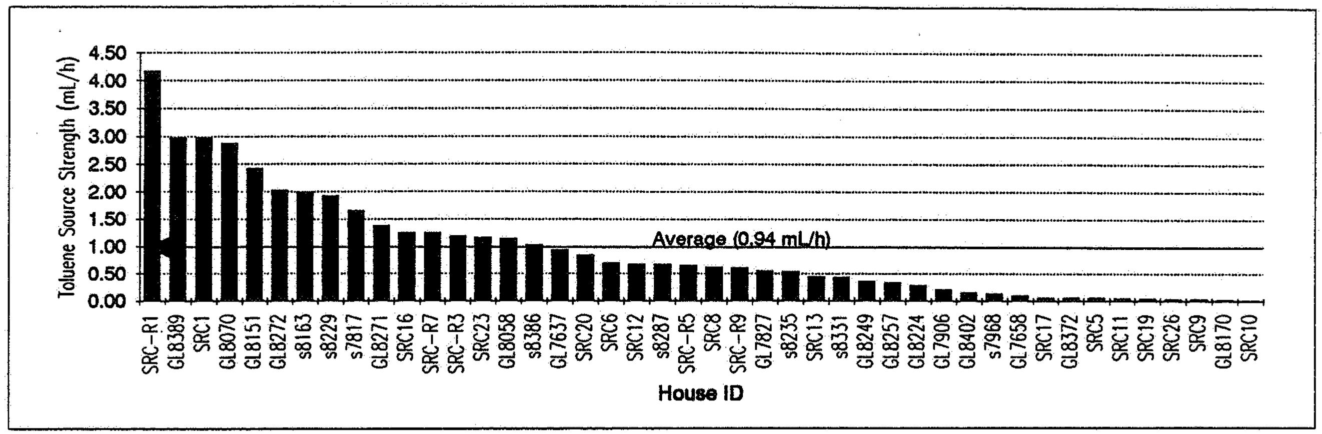
Figure 1.



Whole House Formaldehyde Source Strengths from 1989 Houses (Source: CMHC)

Figure 2.



VOC Whole House Source Strengths (Source: SRC)

Air-tightness Summary

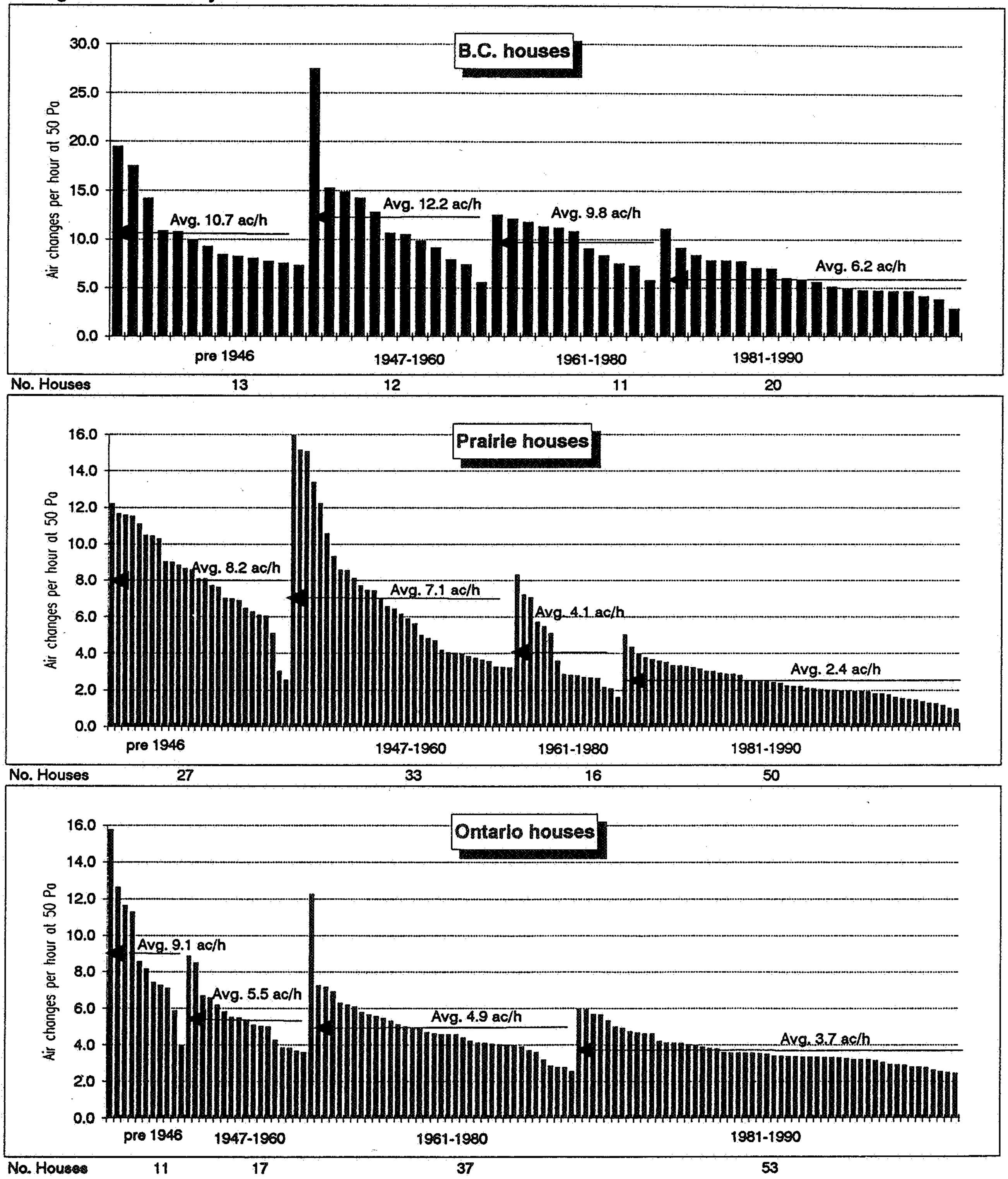


Figure 3.

Indoor Air Quality Profile

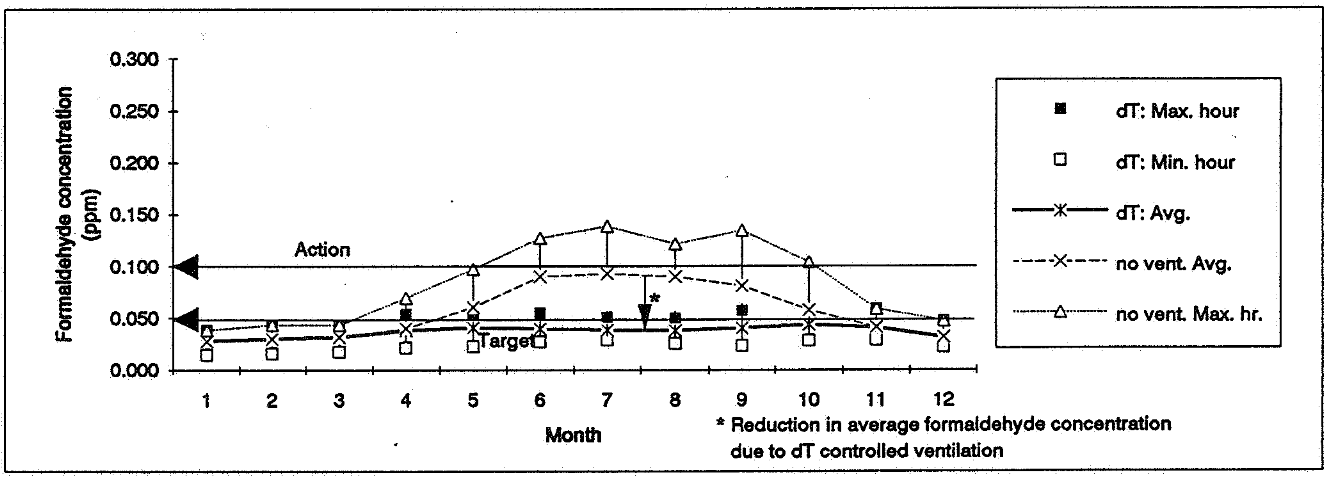
Description:

Region:	ONT	Volume	725 m^3		dT control	no vent.
Age:	1981 to 1990	Bldg. Ht.	6.5 m	Run ID #	66303	66331
Percentile:	75	Flue	none	Infil. Coeff:		
Ventilation Type:	Balanced	Foundation	Bsmt	R	0.60	0.60
Ventilation Flow:	25 L/s	C	169 L/sPa^n	X	0.00	0.00
(Ventilation on if temp. difference		n	0.69	Y	0.00	0.00
to outside <8C, off otherwise)		ELA	3,323 cm^2	Shelter:		
				Building	0.80	0.80

Pollutant Source Strengths:

Whole house source strengths based on: 22 houses

	Formaldehyde	Benzene	Toluene	Xylene	Nonane (mL/hr)	Undecane	Limonene	A-pinene	Ethylbenzene	Source strengths:
House	5.500	0.985	0.856	1.162	N/A	N/A	0.521	0.805	0.385	SRC avg. meas. (whole house)



Pollutant Health Limits (ppm)

	Formaldehyde	Benzene	Toluene	Xylene	Nonane	Undecane	Limonene	a-Pinene	Ethylbenzene	
Classes:	Aldehyde	Aromatic Hydrocarbons			Alkanes		Terpenes		Ether	Class limits are from Seifert
Class Limits:	0.05	0.008	0.007	0.006	0.010	0.008	0.003	0.002	0.002	Aldehyde limit is from EHD
ACGIH TLV	1.00	9	100	100	200	N/A	N/A	N/A	100	(Canada) for formaldehyde.
Predicted Pollutant Concentrations with dT controlled ventilation (ppm)										
Avg: Year	0.037	0.007	0.008	0.008	not avail.	not avail.	0.003	0.005	0.003	
Max: Oct-Apr	0.043	0.008	0.009	0.009	not avail.	not avail.	0.004	0.006	0.003	Highest monthly average for
May-Sep	0.043	0.008	0.009	0.009	not avail.	not avail.	0.004	0.006	0.003	each period
Max. hour	0.059	0.011	0.012	0.012	not avail.	not avail.	0.006	0.009	0.004	

Infiltration & Ventilation: dT control (ac/h) Month

	1	2	3	4	5	6	7	8	9	10	11	12
Max.	0.581	0.541	0.457	0.434	0.416	0.383	0.321	0.384	0.411	0.326	0.327	0.429
Min.	0.173	0.157	0.151	0.104	0.104	0.102	0.102	0.102	0.104	0.102	0.104	0.145
Avg.	0.285	0.267	0.244	0.206	0.191	0.195	0.201	0.201	0.193	0.178	0.191	0.250
Infiltration with no Ventilation (ac/h)												
Avg.	0.285	0.267	0.244	0.196	0.132	0.087	0.085	0.088	0.102	0.141	0.190	0.249

Monthly Average Temperatures (C)

Outside	-8.8	-4.7	-3.0	4.2	12.0	18.2	19.4	19.0	15.6	9.6	4.6	-4.8
Inside	20.0	20.0	20.0	20.0	20.5	22.2	22.6	22.6	21.1	20.1	20.0	20.0

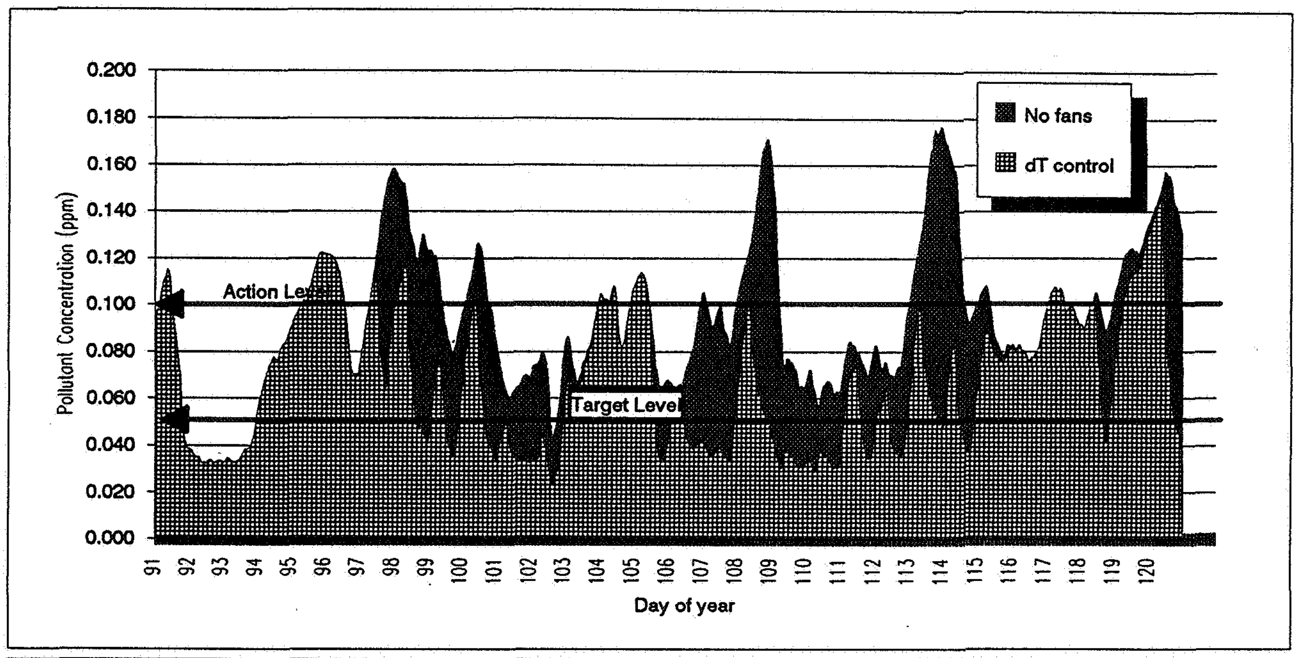
Monthly Average Winds (m/s)

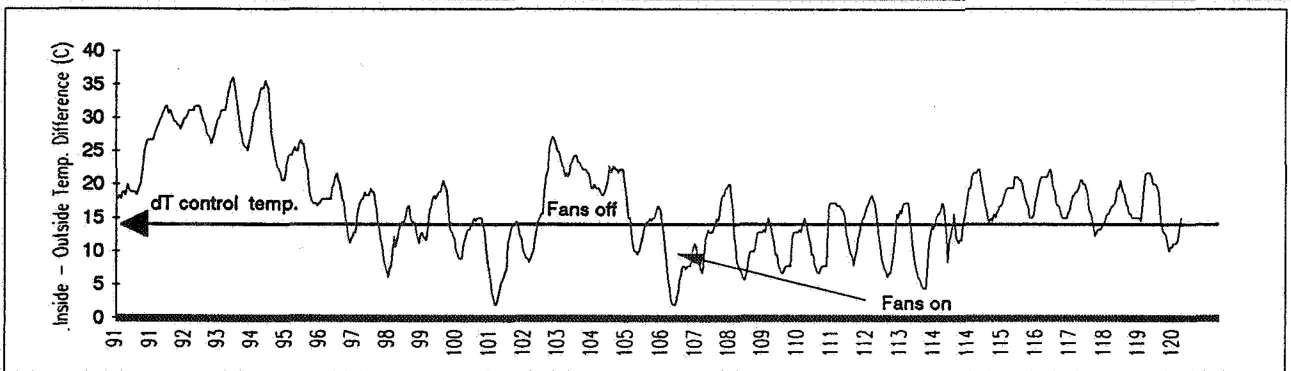
AES Station	5.3	5.8	4.8	4.8	4.0	3.1	3.5	3.5	3.3	3.6	4.8	4.4
Building	2.1	2.3	2.0	1.9	1.7	1.4	1.5	1.5	1.4	1.5	1.9	1.8

Figure 4.

Prairies

April





Formaldehyde concentrations (ppm)

	no Fans	Fans with dT control
Average	0.095	0.068
Minimum	0.033	0.023
Maximum	0.177	0.147

Percentage of hours with concentration greater than limit of 0.1 ppm

no Fans	Fans with dT control
40%	18%

Total infiltration and ventilation

	no Fans		Fans with dT control	
	(ach)	(L/s)	(ach)	(L/s)
Average	0.13	18	0.20	28
Minimum	0.02	3	0.05	7
Maximum	0.44	60	0.55	75

Fan operation: 0 hours | 260 hours

Description:

Source strength: 5.5 mL/h

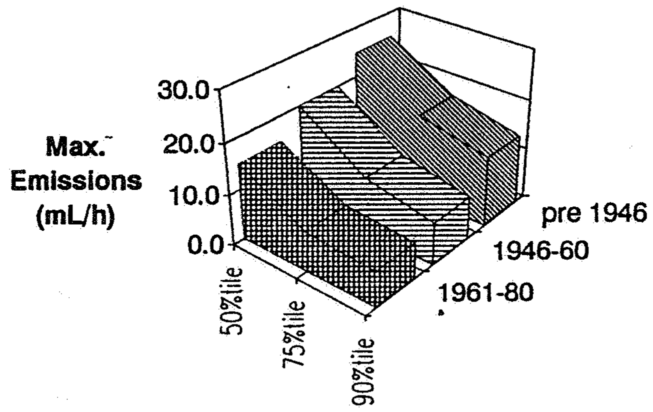
Fans: balanced, 25L/s (with dT control, fans are off unless inside to outside temperature difference is less than 14C)

House:
ID 3630 (no flue)
1981-1990
75th percentile
Volume 494 m^3
C 50 L/sPa^n
n 0.71
ELA 1,030 cm^2
Basement foundation

Figure 5.

Figure **Maximum formaldehyde source strength: B.C.**

Maximum house emissions to maintain concentration below
Action level of 0.1ppm (house closed all year)



	Maximum Emissions (mL/h)			Maximum Emissions (mg/h)		
	50%tile	75%tile	90%tile	50%tile	75%tile	90%tile
1961-80	15.0	8.0	7.2	18.4	9.8	8.8
1946-60	20.0	11.0	8.3	24.5	13.5	10.2
pre 1946	25.0	17.0	13.8	30.7	20.9	16.9

Figure 6.